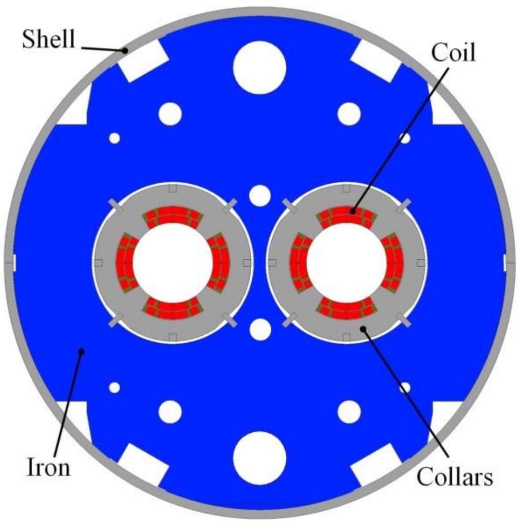
Q4 Protection
Preliminary analysis

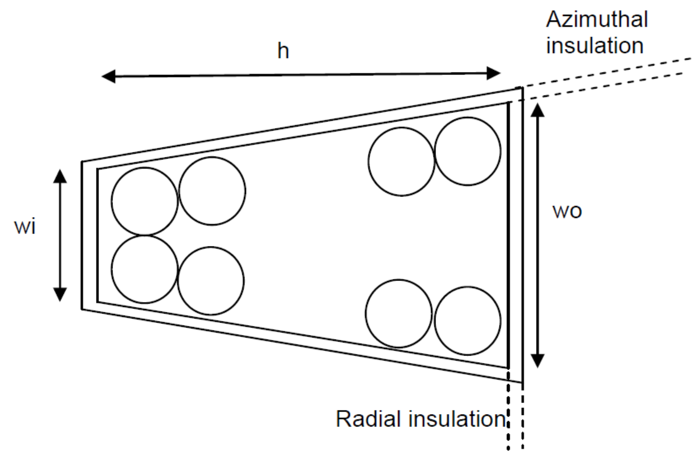


INTRODUCTION

- This presentation talks about the protection of the Q4 quadrupole.
- A first study of the quench protection for the current design of the quadrupole is proposed. Results are shown for <u>**one aperture**</u>
- The study is realised thanks to the software Qtransit based on the M.N.Wilson quench code and which have been developed by CEA for performing quench simulation

INPUTS

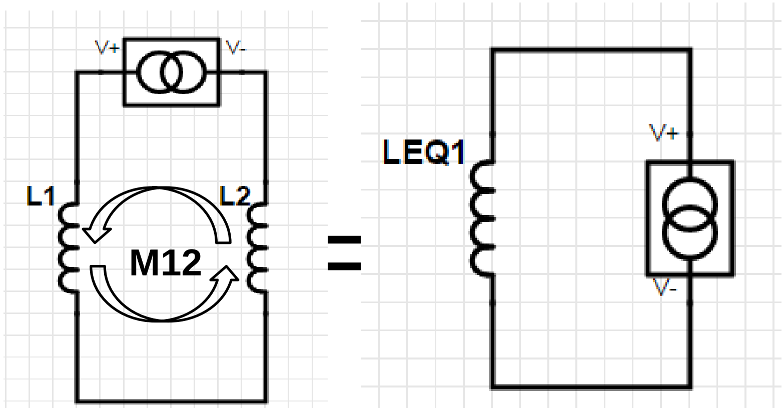
Q4 Cable	
h	8.8 mm
wi	0.77 mm
wo	0.91 mm
Strand diameter (d)	0.475 mm
N strand	36
Radial insulation (e)	0.08 mm
Azimuthal inslation (e)	0.08 mm
Insulated cable crosss section	8.960 mm^2



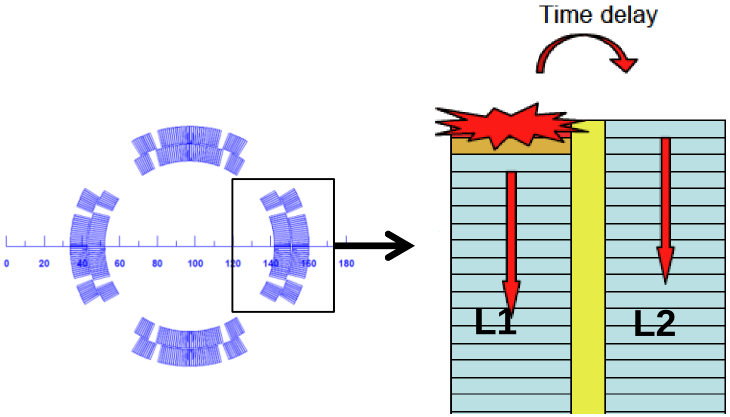
Detection threshold	0,1 V	These values have been confirmed by CERN (Mail from E.Todesco 08/03/2016)
Validation time	10 ms	
Maximum Hotspot temperature allowed	< 250K	These values are conservatives (Mail from B. Auchmann 09/03/2016)
Maximum voltage to ground allowed	800 V	

HYPOTHESIS

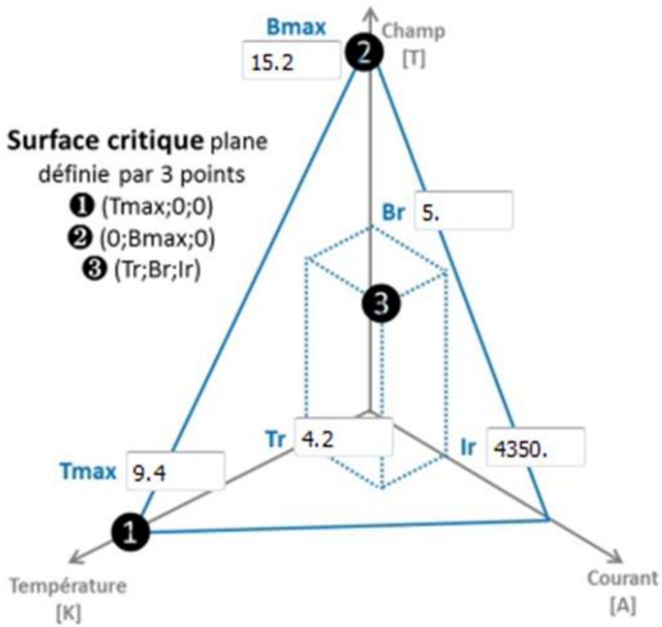
- To simulate the quench propagation for the Q4 magnets we used a model of two coils where the first coils represent the inner layer of the 4 coils and the second coils represent the outer layers.
- The two layers are separated by a G10 shim of 0,5 mm which delays the thermal conduction between the two layers.
- The total volume of the 4 coils and the total energy are accounted for. QH are fired on all coils.

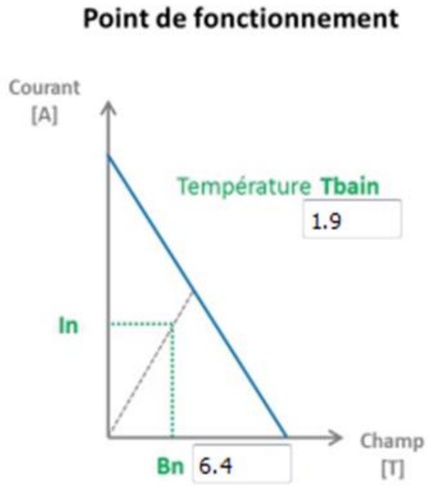


$$L_{eq1} \approx L_1 + L_2 + 2M_{12}$$



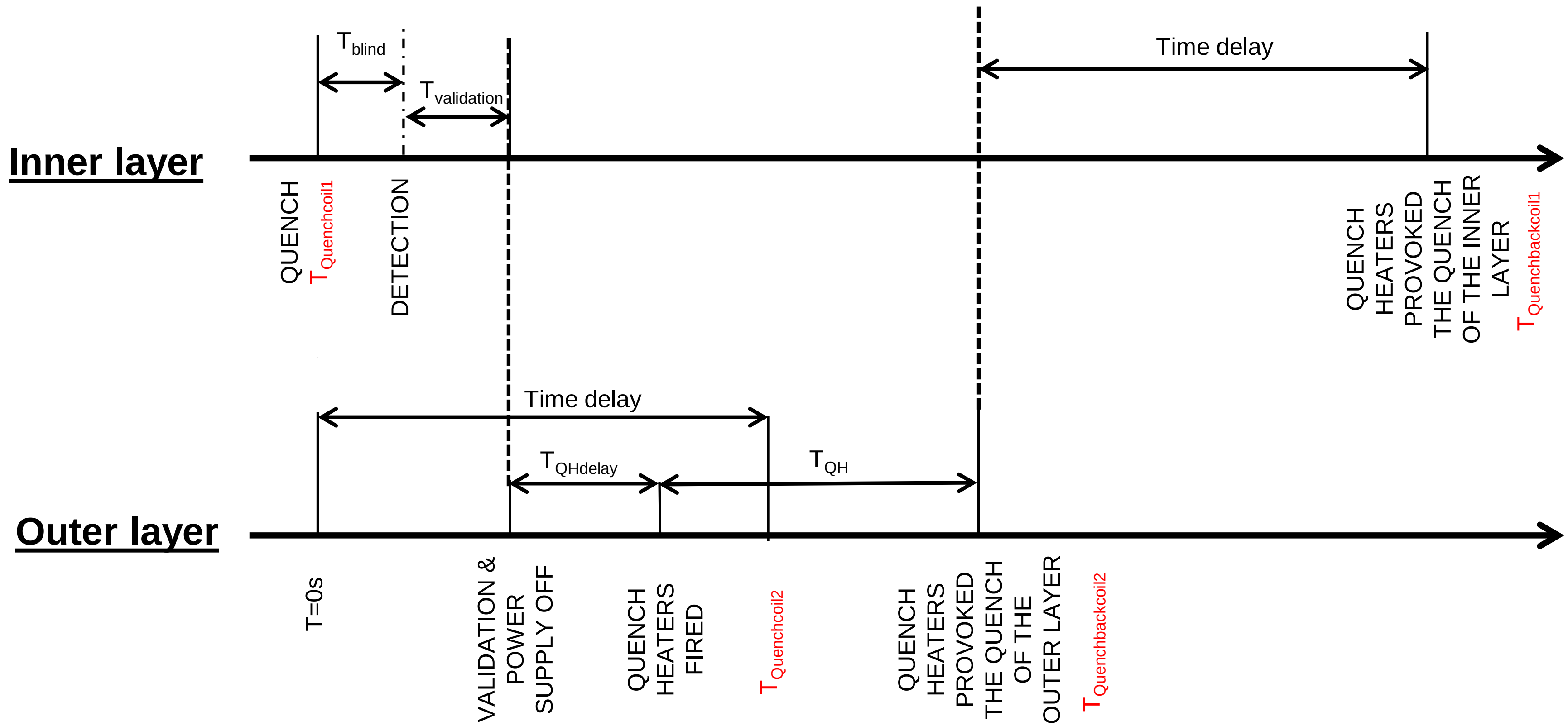
- The critical surface of the Q4 wire in NbTi is given in the following graph:



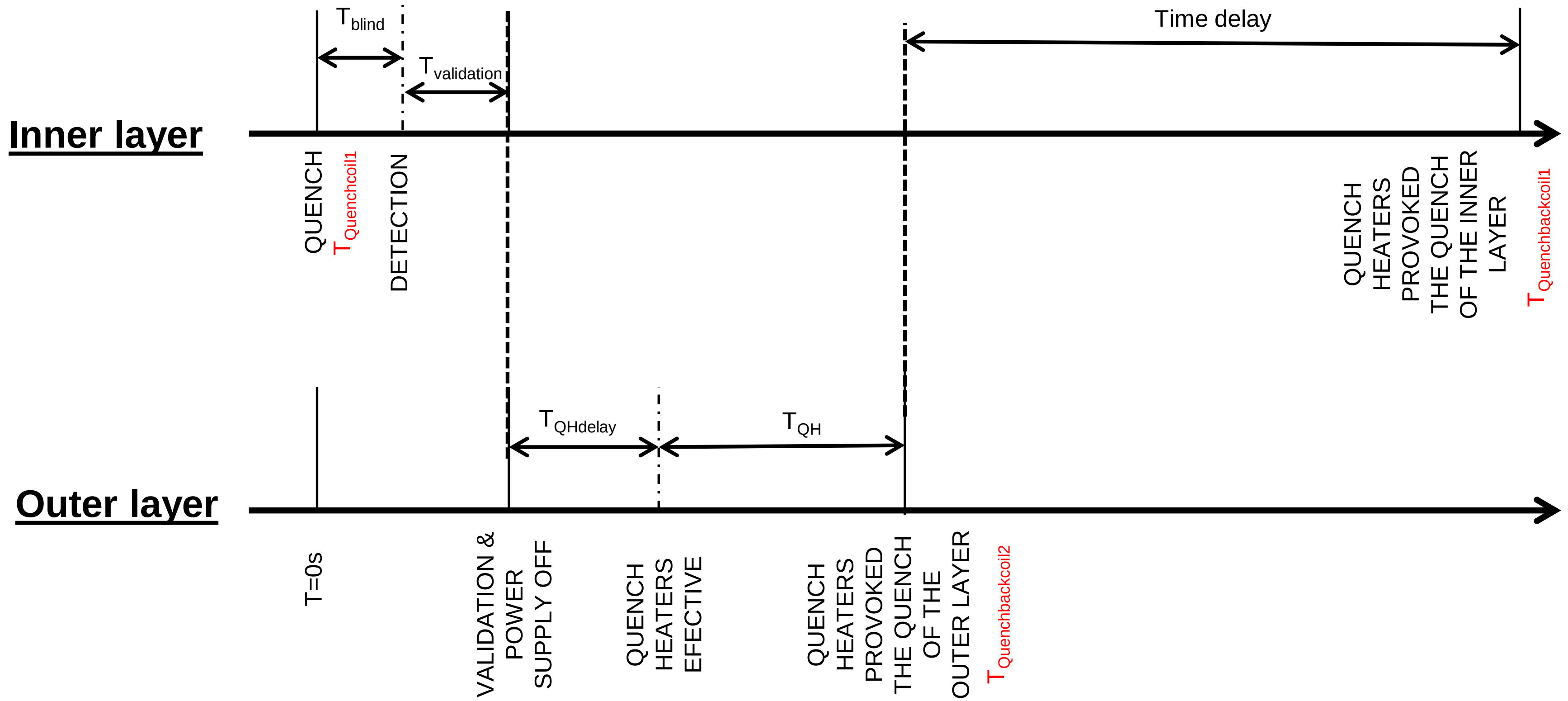


DEFINITIONS OF THE VARIOUS TIME DELAYS

Case 1:The outer layer quenches before the quench heaters provok a quench



Case 2: The outer layer quenches when the quench heaters provok a quench



SIMULATION TOOLS: QTRANSIT

- Qtransit is a CEA software based on the M.N.Wilson quench code.
- The Qtransit program calculate the thermodynamics of a coil when a quench occurs.
- The temperature rise at the initial quench point define in the inputs. After calculation the code gives the final temperatures inside the winding and the voltage induced
- The geometry and the materials of the cable are given in the inputs

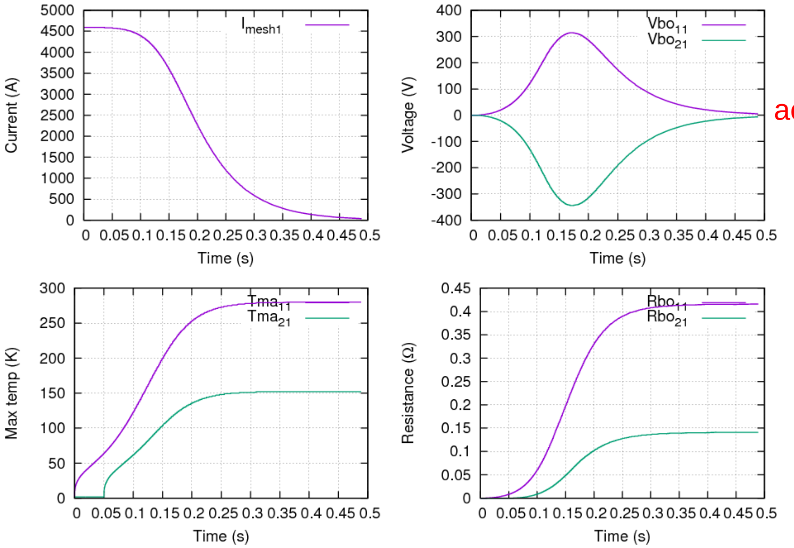
HYPOTHESIS

- The mutual inductances have been found by using the ROXIE code
- The layer-to-layer time delay of 75ms has been estimated thanks to a 1D transient finite elements method. The simulations have been made for a time delay of 50ms, 75ms and 100ms
- The simulations have been made with and without quench heaters.

Hypothesis	
L1	$9{,}21^{E-3}$ H
L2	$12{,}34^{E-3}$ H
M12	$8{,}55^{E-3}$ H
LEQ1	$37{,}55^{E-3}$ H
I	4590 A
Quench Heater	Placed on the outer layer
$T_{quenchcoil1}$	0 s
T_{blind}	6 ms
$T_{validation}$	10 ms
$T_{quenchcoil2}$	6+10+40=56 ms
$T_{quenchbackcoil2}$	56 ms
$T_{quenchbackcoil1}$	75+56=131ms
T_{delay}	≈ 75ms
$T_{QH}+T_{QHdelay}$	40 ms (to be verified)

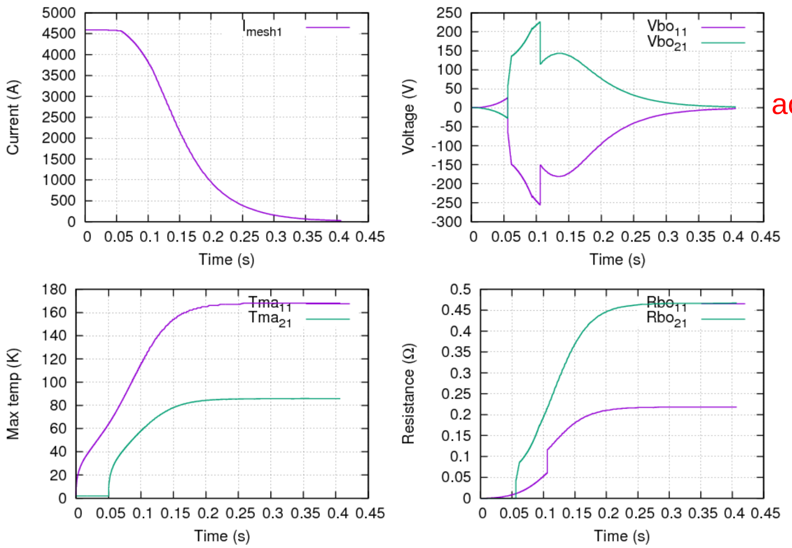
SIMULATION

Hypothesis	
Without quench heater	
Time delay	50 ms
Maximum Hotspot temperature in coil 1	279,9 K
Maximum Hotspot temperature in coil 2	152,4 K
Maximum voltage to ground	547,8 V



Voltage accross each layer

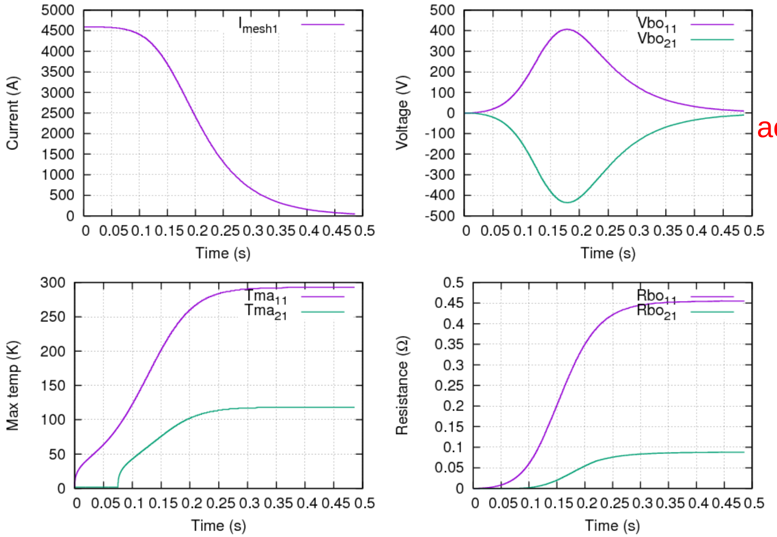
Hypothesis	
With quench heater	
Time delay	50 ms
Maximum Hotspot temperature in coil 1	167,9 K
Maximum Hotspot temperature in coil 2	85,8 K
Maximum voltage to ground	340,2 V



Voltage accross each layer

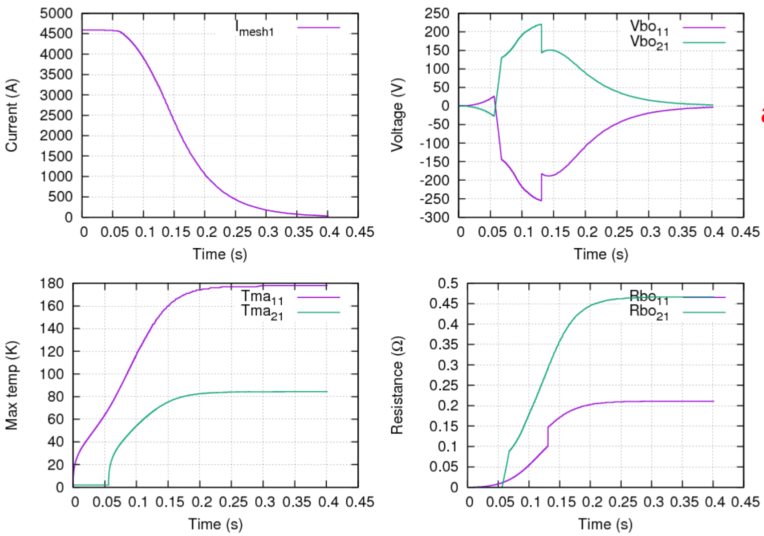
SIMULATION

Hypothesis	
Without quench heater	
Time delay	75 ms
Maximum Hotspot temperature in coil 1	293 K
Maximum Hotspot temperature in coil 2	118,3 K
Maximum voltage to ground	594,6 V



Voltage accross each layer

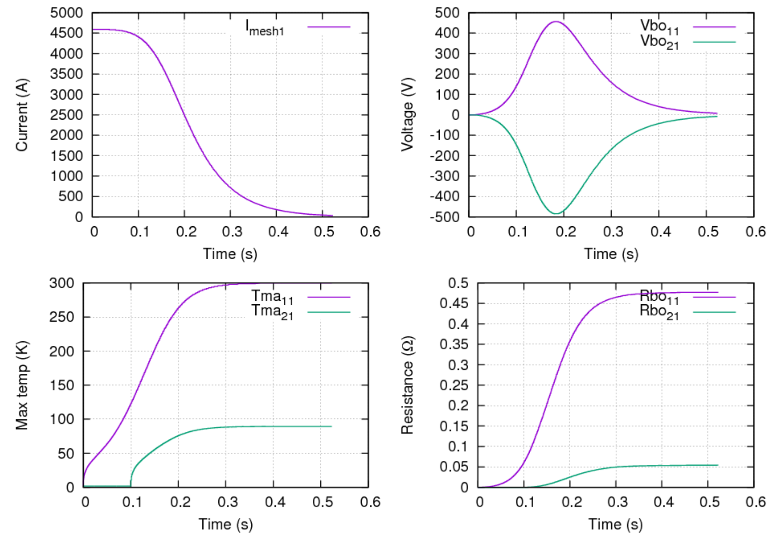
Hypothesis	
With quench heater	
Time delay	75 ms
Maximum Hotspot temperature in coil 1	177,6 K
Maximum Hotspot temperature in coil 2	84,3 K
Maximum voltage to ground	340,2 V



Voltage accross each layer

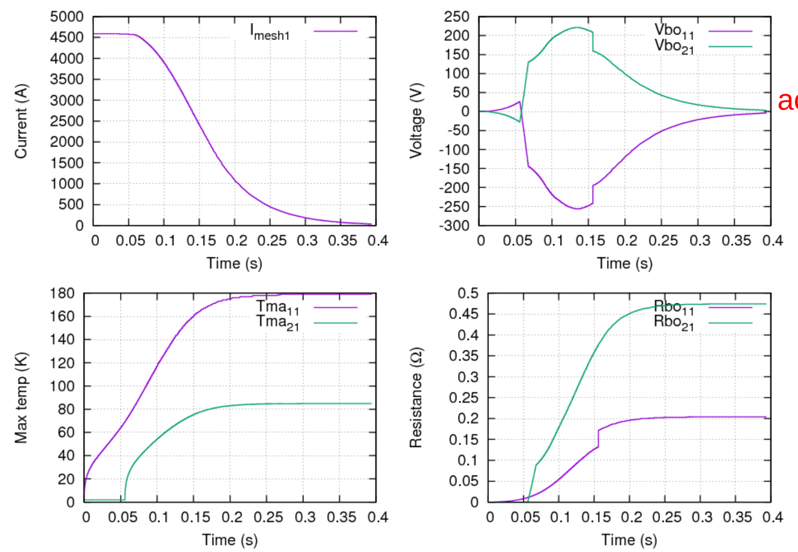
SIMULATION

Hypothesis	
Without quench heater	
Time delay	100 ms
Maximum Hotspot temperature in coil 1	300,1 K
Maximum Hotspot temperature in coil 2	89,4 K
Maximum voltage to ground	634 V



Voltage accross each layer

Hypothesis	
With quench heater	
Time delay	100 ms
Maximum Hotspot temperature in coil 1	178,9 K
Maximum Hotspot temperature in coil 2	84,9 K
Maximum voltage to ground	340,2 V



Voltage accross each layer

RESULTS

Results						
	Without quench heater			With quench heater		
Time delay	**50 ms**	**75 ms**	**100 ms**	**50 ms**	**75 ms**	**100 ms**
Maximum Hotspot temperature in coil 1	279,9 K	293 K	300,1 K	167,9 K	177,6 K	178,9 K
Maximum Hotspot temperature in coil 2	152,4 K	118,3 K	89,4 K	85,8 K	84,3 K	84,9 K
Maximum voltage to ground	547,8 V	594,6 V	634 V	340,2 V	340,2 V	340,2 V

CONCLUSION

- The QTRANSIT code has been used on the updated version of Q4.
- Simulations with and without QH have been carried out

- The highest hot spot temperature (300 K) is reached in absence of QH and with a layer-to-layer time delay of 100 ms.
- With QH:
    - the hotspot is limited to ~180 K.
    - The max V to ground is ~340 V

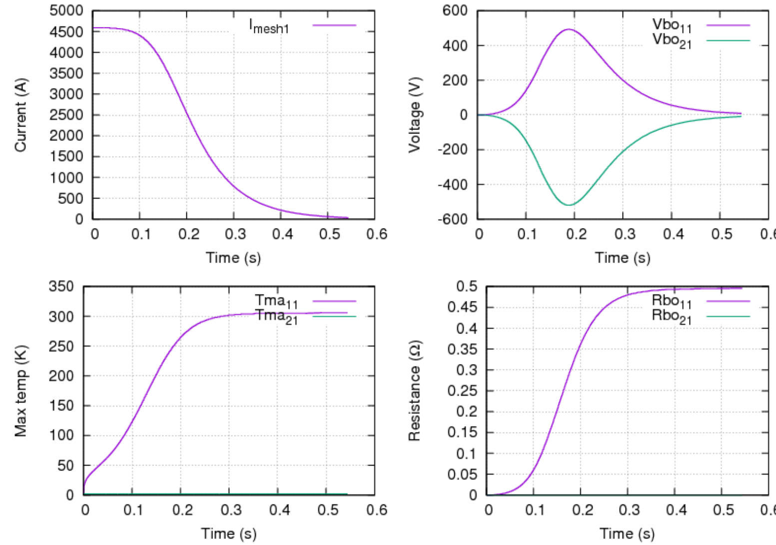
- Next steps:
    - Simulation with ROXIE
    - Detailed design of the QH: high/low field, strip design and number of circuits

OPEN QUESTIONS

- Powering scheme of the Q4?
- Number of heaters PS

ANNEX

Hypothesis	
Without quench heater	
Time delay	infinite
Maximum Hotspot temperature in coil 1	305,6 K
Maximum Hotspot temperature in coil 2	1,9 K
Maximum voltage to ground	687,4 V



Hypothesis	
With quench heater	
Time delay	100 ms
$T_{QHdelay}+T_{QH}$	60 ms
Maximum Hotspot temperature in coil 1	210,7 K
Maximum Hotspot temperature in coil 2	78,7 K
Maximum voltage to ground	634 V